HAASE

The Distribution of Water in Reservoirs by Means of Orifices

Municipal & Sanitary Engineering:
B S
1906

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class Book Volume

1906 H11

Je 06-10M

78/
H5
H65

THE DISTRIBUTION
OF
WATER IN RESERVOIRS
BY MEANS OF ORIFICES

BY

HERBERT EMIL HAASE

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

MUNICIPAL AND SANITARY ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1906

11H
1906

1906
H11

UNIVERSITY OF ILLINOIS

June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HERBERT EMIL HAASE

ENTITLED THE DISTRIBUTION OF WATER IN RESERVOIRS BY MEANS OF ORIFICES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Municipal and Sanitary Engineering

A. N. Talbot

HEAD OF DEPARTMENT OF Municipal and Sanitary Engineering

88100

UIUC

The Distribution of Water in Reservoirs by Means of Orifices.

I. Introductory.

Settling-basins for the sedimentation of water, of the continuous flow type are similar to septic tanks in that the water or sewage flows in at one point, undergoes a change or process while in the containing vessel, and finally flows out at another point. It is evident that any portion of the settling-basin or tank which in no way has an effect upon the process involved is a useless adjunct; worse than useless, as it is an item of expense in construction and maintenance, often in an amount beyond the ordinary conception. Any portion of a tank through which no flow occurs is useless. Besides, the efficient operation of such a tank requires a uniform velocity throughout

Digitized by the Internet Archive
in 2013

http://archive.org/details/distributionofwa00haas

its length. Hence it will be seen that it is of primary importance to make every portion useful and to secure a uniform distribution of the flow through out the entire cross-section of the tank. An important element in accomplishing this lies in the design and arrangement of the manner of entrance and exit of the water or sewage in a basin of this nature. Consider a settling-basin built at a cost of $100,000. It is not hard to imagine conditions to be such that the flow occurs through a portion consisting of two-thirds of the cross-section. In this case $33,000 would represent the amount invested and being put to no use; a large premium to pay on the incorrect design of inlet. It is probable that basins are in existence in which less than one-half of the volume which should be available is effective and the inlet and outlet would utilize the full working-capacity of the tank and increase its utility. It will be seen that to obtain ideal conditions

of flow, a piston-like movement of a vertical section of water is important.

The devices for the entrance of water into a tank may be grouped in two classes, weirs and orifices. The weir has the advantage over the orifice in that the distribution of the influx may be extended over the entire cross-section of the breadth of the tank, and thus uniformly distributed laterally; but this does in no way provide for the distribution of the influx throughout the depth. This is an evident shortcoming of the weir for use as an inlet. However, it is essential in both settling-basins and septic tanks a constant level be maintained. This is usually accomplished by providing a weir at the outlet. It may be so baffled as to prevent the effluent from running off of the immediate surface. This is a common method of arrangement, orifices at entrance and a weir at exit. An examination of various articles in

available engineering periodicals shows this to be true for septic tanks. Of twenty septic tanks described, eighteen have this arrangement and the other two have devices not entirely different but falling under classification of slotted pipes as patented by the Cameron Septic Tank Company.

To ascertain the characteristic flow of water through orifices, and the effect of the shape of the orifice upon the distribution of the influx throughout the cross-section of the tank, a series of experiments were made. These will be explained and discussed and the information gained will be applied by suggesting forms and limitations for inlets and outlets of reservoirs.

II. Experimental.

An aquarium, a prismoidal vessel, with glass sides and ends, whose cross-section was 17" X 12" and length 20" was fitted up with a partition wall about 2½" from one end. At the mid-point of this partition was located an orifice, through which a flow might be created from

one chamber into the other. A tube in the smaller compartment served as a means of supply of water. The water might then be drawn from the end of the larger compartment by means of a siphon-tube, thus creating a flow through the orifice. By adjustment of the siphon a condition may be determined at which a constant level would be maintained. Filling the two chambers with water, the water in the smaller one was colored a vivid green by means of fluorescein, a strong coloring matter which readily mingles with water. Then starting a flow through the orifice in the manner described above, it was possible by observing the fall of the coloring matter to determine the character of the flow in reference to distribution. It was necessary to have some standard condition prevailing so that these results might be comparable. This condition, observed in all experiments with this tank was that the time elapsing between the occurrence of influx of the coloring matter until exit

be two minutes.

Experiment 1. Figure 1 represents the apparatus as assembled and the orifice which, as shown, was shaped like the frustrum of a pyramid, expanding from 3/4" x 3/4" to 1½" x 1½". The sides formed an angle of 20° with the horizontal axis. A level within 1½° of the top of the tank was maintained. The flow, as shown, expanded so that in its largest section it occupied about one third of the section of the tank. A composite sketch of the observations is shown in Figure 1.

Experiment 2. The level of the water was then reduced to the middle of the orifice and the supply decreased so that the former velocity of two minutes for the flow was again obtained. Under these conditions the distribution throughout the breadth was quite complete but not so throughout the depth. The flowing water clung to the surface and seemed inclined to slip over the top in a sheet. The composite result of ten observations is shown in figure 2.

Experiment 3. The same two experiments were again performed with a rectangular slotted orifice, about 1½" x ½" in size. The lips of this orifice were sharp and the stream issuing from it was undisturbed and clear cut. The result of the ten observations as shown in figure 3, indicate that a horizontal distribution is more easily accomplished than a vertical distribution.

Experiment 4. When this orifice was submerged to the middle it was again evident that the flow has a tendency to occur in a film over the surface. This is clearly illustrated in figure 4.

These results were in a measure verified by the following experiments conducted on a larger scale.

Experiment 5. Coloring matter was introduced into a six inch pipe, thirty inches long, which connected two chambers of a larger size. This apparatus is shown to scale in figures 5 and 6. In the first case the pipe had no expansion at its outlet and the course of the water was directly

parallel to the horizontal axis of the jet until it banked against the wall at the end of the chamber. This is shown in Figure 5.

Experiment 6. In the second case the jet had an expander on its mouth that increased its diameter from six to ten inches in a distance of eight inches. This forms an angle of 14° with the horizontal axis. In this case the flow was not concise but broken and inclined to spread as it left the orifice in a way similar to its action in the corresponding experiment when performed on a smaller scale.

Experiment 7. This orifice was then replaced by another which increased in diameter from six inches to eight and one half in seven and one half inches. This made an angle of 10° degrees with the horizontal axis of symmetry. This orifice caused in a manner similar to the last experiment. an expansion of the flow

however it was evident the flow clung to the sides of the orifice, a thing that did not occur with the larger experiment This caused me to believe that ten degrees is probably the desired increase for an orifice of this nature. One of a higher degree would be inclined to cut the water as in figure 3 and not direct it on its diverging path. The velocities in these cases were about nine foot per second.

Experiment 8. Experiments of this nature were done with the two styles of orifices. Experiment 9 with the water-line at the center of the pipe. These are shown in figures 8 and 9. It was again perceptible that the water is inclined to strike on the surface and not invade the zones below the inlet.

The introduction of coloring matter was accomplished by means of a series of nozzles inserted in the inlet of the tube These were connected to a reservoir of coloring matter The entire was composed of 1/4 inch pipe and illustrated in figure 7.

III. Discussion of Experiments.

Viewing the subject from an approximate mathematical standpoint; we have the following.

General Data for Small Tank.

Cross section of the tank ——— 1 sq. ft.

" " " " expanding orifice — .0039 " "

" " " " rectangular " — .0057 " "

Quantity of water flowing through tank — .00026 $\frac{\text{cu. ft.}}{\text{sec.}}$

" " " " " " — 1 $\frac{\text{lb.}}{\text{min.}}$

Experiment I., Figure I.

$$\text{Velocity} = \frac{\text{Quantity.}}{\text{Area.}}$$

$$\text{Velocity at orifice} = \frac{.00026}{.0039} = \frac{1}{14.6} \text{ ft./sec.}$$

Assuming area at a, 1/3 of entire, Velocity at $a = \frac{.00026}{333} = \frac{1}{1250}$ ft./sec.

Assuming area at b, 1/4 of entire, Velocity at $b = \frac{.00026}{.25} = \frac{1}{940}$ ft./sec.

$$\text{Average Velocity in tank} = \frac{\frac{1}{14.6} + \frac{1}{1250} + \frac{1}{940}}{3} = \frac{1}{40} \text{ ft./sec.}$$

Actual observed velocity $= \frac{3}{4}$ ft./min. $= \frac{1}{80}$ ft./sec.

Comparing the two velocities $\frac{1}{40}$ ft./sec. and $\frac{1}{80}$ ft./sec.; thus upon the condition that areas at a, b and c are representative, it would indicate that the areas are actually larger than those assumed.

Experiment 2, Figure 2.

$$\text{Velocity} = \frac{\text{Quantity}}{\text{Area}}, \quad \text{Quantity} = .000173 \text{ cu. ft./sec.}$$

$$\text{velocity at orifice} = \frac{.000173}{.5 \times .0039} = 1/44 \text{ ft./sec.}$$

Assuming area at a, 1/4 of whole; Velocity at a $= \frac{.000173}{.5 \times .25} = 1/705$ ft./sec.

Assuming area at b, 1/5 of whole, velocity at b $= \frac{.000173}{5 \times .2} = 1/550$ ft./sec.

$$\text{Average Velocity} = \frac{1/44 + 1/705 + 1/550}{3} = 1/116 \text{ ft./sec.}$$

Actual Velocity = 1/80 ft./sec.

Comparing the two velocities 1/116 ft./sec and 1/80 ft./sec.; thus upon the condition that areas at a, b and c are representative; it would indicate that the areas were actually smaller than assumed.

Experiment 3, Figure 3

$$\text{Velocity} = \frac{\text{Quantity}}{\text{Area}}, \quad \text{Quantity} = .000173 \text{ cu. ft./sec.}$$

$$\text{velocity at orifice} = \frac{.000173}{.0052} = 1/30 \text{ ft./sec.}$$

Assuming area at a, 1/6 of whole, Velocity at a $= \frac{.000173}{1/6} = 1/935$ ft./sec.

Assuming area at b, 1/6 of whole, Velocity at b $= \frac{.000173}{1/6} = 1/935$ ft./sec.

$$\text{Average velocity} = \frac{1/30 + 1/935 + 1/935}{3} = 1/85 \text{ ft./sec.}$$

Actual velocity = 1/80 ft./sec.

Comparing the two velocities 1/85 ft./sec and 1/80 ft./sec.; thus upon the condition that areas at a, b and c are representative, it would indicate the areas at these points were actually the same as those assumed.

Experiment 4, Figure 4.

$$\text{Velocity} = \frac{\text{Quantity}}{\text{Area}}, \quad \text{Quantity} = .000173 \text{ cu. ft./sec.}$$

$$\text{velocity at orifice} = \frac{.000173}{.5 \times .0052} = \frac{1}{58.5} \text{ ft./sec.}$$

Assuming area at a, 1/6 of whole, velocity at a. $= \frac{.000173}{.5 \times 1/6} = \frac{1}{470}$ ft./sec.

assuming area at b, 1/6 of whole, velocity at b. $= \frac{.000173}{.5 \times 1/6} = \frac{1}{470}$ ft./sec.

$$\text{Average velocity} = \frac{\frac{1}{58.5} + \frac{1}{470} + \frac{1}{470}}{3} = \frac{1}{138} \text{ ft./sec.}$$

$$\text{Actual velocity} = \frac{1}{80} \text{ ft./sec.}$$

Comparing the two velocities 1/138 ft./sec and 1/80 ft./sec.; then upon the condition that the areas at a, b and c are representative, it would indicate that the areas were actually smaller than assumed.

Experiments 5, 6, 7, 8 and 9.

These experiments substantiate the general results obtained and observed in the first four experiments. They verified the fact that the expansion of an orifice caused an expansion and divergence of the flow from it. However it was observed that with a too rapid a flare or divergence of the sides of the orifice, the flow will not continue in the lines directed by the orifice. This was the result with the 14° expander. However, the one with the

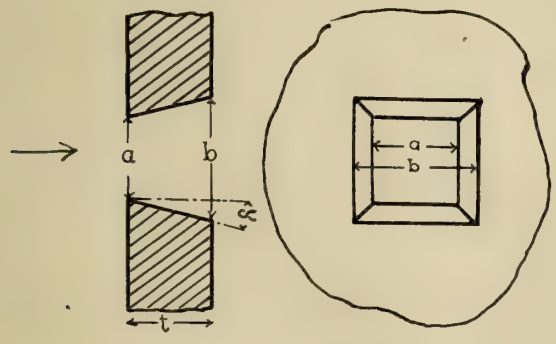
smaller angles showed that ten degrees angle of divergence will give good results. It did not "cut" the flow but the water seemed to cling to the sides of the orifice, and continued to expand after leaving the orifice. This is an invaluable feature and upon it the completeness of the expansion and the full direction of the current beyond depends the value and afflicability of the orifice. These four experiments also verified the observations on the smaller experiments concerning the slipping of the water over the surface when the orifice is not submerged. It is very evident that water when subjected to these conditions has a decided tendency to flow in a film over the surface and not to be distributed to any considerable depth.

IV. General Discussion.

The average of the computed and observed velocity in the tank used in experiment I was 1/60 of a foot per second, or one foot per minute. This velocity in a tank one hundred feet long would result in an actual flow of an hour and three quarters. This lies within

the range of probable velocities in a septic tank or settling-basin, and shows the applicability of the results of the experiments to actual conditions. The details of the design of the orifice will now be discussed. It has been shown that the desired distribution of flow may be obtained by means of a properly proportioned orifice. A relation governing conditions or dimensions will now be derived.

Let us consider the orifice shown in the accompanying illustration. The flow is to occur in the direction indicated by the arrow. The thickness of the wall in which it is to be placed may be taken as t. Then consider the dimension of the square representing the inlet to be a, and of the outlet b. The angle of diverging side with the horizontal axis is α. The experimental orifice which proved in the most satisfactory in experiment 7 was the ten degree expander. This orifice increased in diameter from



six to eight and one-half inches in seven and one half inches. The ratio of the smallest to the largest cross-section was then $\frac{28}{56}$ or $1/2$.

It has been demonstrated by Messrs. Wiley and Robinson at the University of Illinois that there is little loss of velocity head in the occurance of a flow through the ten degree expander.

Setting the above ratio govern the example under consideration, the equation $b^2 = 2a^2$ would represent conditions. It may be seen from the figure that $\tan \alpha = \frac{b-a}{2t}$. As ten degrees has been decided upon as the desirable angle, let us substitute its tangent .2 in the relation derived

$$\tan \alpha = \frac{b-a}{2t}, \text{ or } \frac{b-a}{2t} = .2, \text{ or } b-a = .4t.$$

Now as $b^2 = 2a^2$, $b = \sqrt{2}\, a$

Substituting $\sqrt{2}\, a$ for b, we have

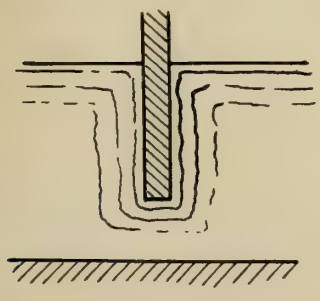
$$(\sqrt{2}-1)\, a = .4t \text{ or } (1.41-1)a = .4t$$

This gives approximately, $a = t$.

This relation interpreted states that for the condition that the area of the outlet is twice the area of the inlet and the angle

of expansion is ten degrees, the side of the square inlet will be equal to thickness of the wall.

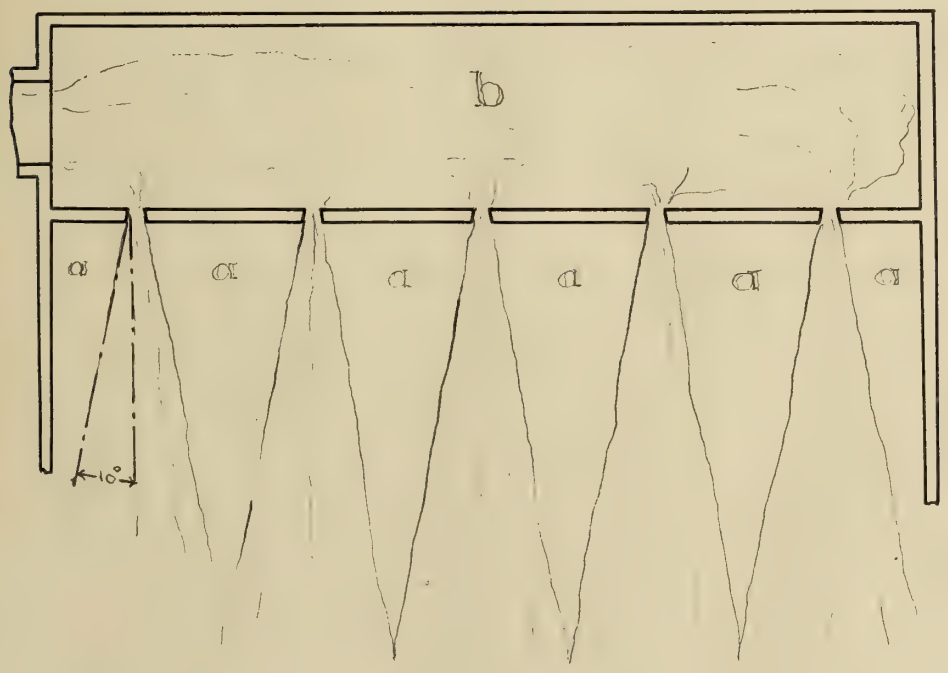
The nature of the flow through a semi-submerged orifice has been discussed and may be defined as surface skimming. It is evident that the momentum of the stationary water is so great that the velocity of the inflowing stream will be expended upon the surface rather than in pulling the water throughout the depth in motion. Should any such means of inlet be used it would be necessary to provide an efficient system of baffling. Baffling could scarcely accomplish the desired results, as it is true that water will flow under a baffle in a manner similar to the flow over a submerged weir. The momentum of the stationary water again causes the velocity to be expended over the surface of the tank and directly next to the baffles.



This is shown in the accompanying figure. So it will be seen that baffles will not create that condition of ideal flow we are now designing to accomplish.

V. Application to Design.

The application of these features of design to reservoirs will now be considered. Having decided upon an orifice of expanding section and upon the proportions governing its dimensions and form, we will now investigate the spacing of the orifice. It is desirable to get the flow from the individual orifices into a unit-flow, or uniform current over the full depth in the shortest length possible. This is a matter of decided economy in the capacity of the tank.



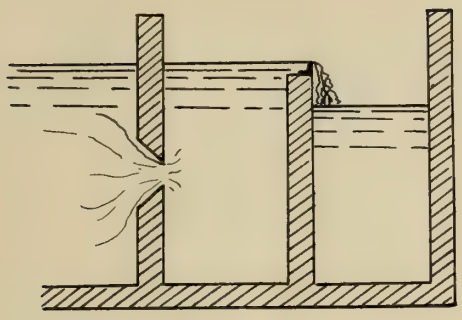
In the figure on the preceding page, the spaces a are the "useless adjuncts" which in no way add to the performance of the tank's duties These spaces increase in size as the spacing of the orifices is increased Thus it may be seen that the economical spacing involves the comparison of the cost of the tank per linear foot and the cost of the construction of an orifice. It has been shown that the spacing can only be designed by the careful consideration of this comparison. However there is a minimum desirable distance between orifices as too close spacing would be uneconomical. A spacing equal to the depth of the tank or reservoir is recommended In this case the horizontal expansion required would be equal to the vertical expansion a condition quite satisfactory to distribution In this case the flows from the various orifices would become unified at a distance from the orifice equal to two and one half times the depth of the tank, or the spacing of the orifices. However it would not be decidedly disad-

analogous to the process of the tank or basin if the horizontal expansion were considerably in excess of the vertical expansion, as the latter is limited by the surface of the water and the bottom of the tank.

In the figure on page 17 it is shown that the duct b be a channel of considerable width. This is necessary to insure an equal subsidy of water at all orifices and a low velocity at the entrance to the orifice.

The devices for the exit of the water from the reservoir is also to be considered. It is nearly as important that the water leave the tank in a vertical sheet as it is that it enter in this manner. If the water is drawn off over a weir at the extreme end, it is sure to disturb the conditions of flow installed at entrance. If it drawn over a weir and from under a baffle it will effect it in a similar manner, but not to such a marked degree. Experiments conducted at the University of Illinois have demonstrated that a contracting orifice will collect the water from a surprisingly large area in the process of "running through" Such a device as shown in the accompanying illustration

Sectional Elevation.



is recommended. The surface contracting at angle of forty-five degrees will collect the water from the entire sectional area and the weir b will maintain a constant water level, a thing usually desired in works of the character under consideration.

Figure 10 shows an application of the conclusions concerning orifices as a means of entrance and exit of the liquid into a reservoir. The features embraced are;

1. The entrance orifice is expansive in cross-section, its sides making an angle of ten degrees with the horizontal axis.
2. The smallest dimension of the orifice is equal to the thickness of the wall in which it is placed.
3. The entrance of the orifice is located midway between the surface of the water and the bottom of the tank.
4. The horizontal spacing is equal to the depth of the tank.
5. The outlet orifices are contractive in cross-section and the sides make an angle

of forty-five degrees with the horizontal axis 6. The outlet orifices are located in the end-walls in positions similar to the inlet orifices.

7. The constant water-level is maintained by a weir-wall behind the outlet orifices.

General practice debarts widely from the recommendations made in the previous paragraph.

Considering a specific case of a representative continuous sedimentation-basin, the one operated in connection with the water-filtration works at Albany, New York. The inlet and outlet pipes range along the the opposite long sides of the rectangular shaped basin. The tank is nine feet deep and the inlets are fifty-five feet apart. The distance between the inlet and the corresponding outlet is about three hundred and seventy-five feet. The general form of the inlet is a vertical overflowing pipe extending four feet above the surface of the water. The outlet is a similar pipe two feet below the surface. It is believed that this reservoir with such conditions of inlet and outlet cannot have the desired

conditions of uniform velocity imperative to the efficient operation.

The settling tank to be constructed in connection with the sewage disposal works at Columbus, Ohio in no way embraces the features herein recommended. This tank is divided into compartments forming a primary and secondary systems. The inlets and outlets are both submerged orifices, but consist wholly of circular sluice-gates. They are spaced about fifteen feet apart; the depth of water in the tank fluctuating from twelve to nine feet. These sluice gates are twenty-four inches in diameter and it may be submitted that the flow will be similar to that portrayed in figure 3.

Engineering has been defined as "economical construction", and an engineer worthy of that title should strive for improvements involving economic gain. This subject considered is a feature of engineering which, it is believed, has not received the attention and care warranted by its importance and the expenditures involved.

Fig. 1.

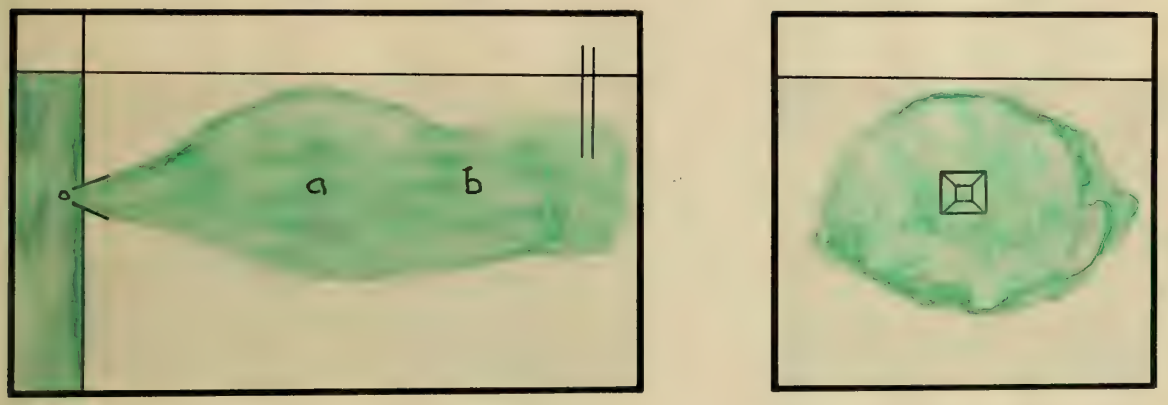
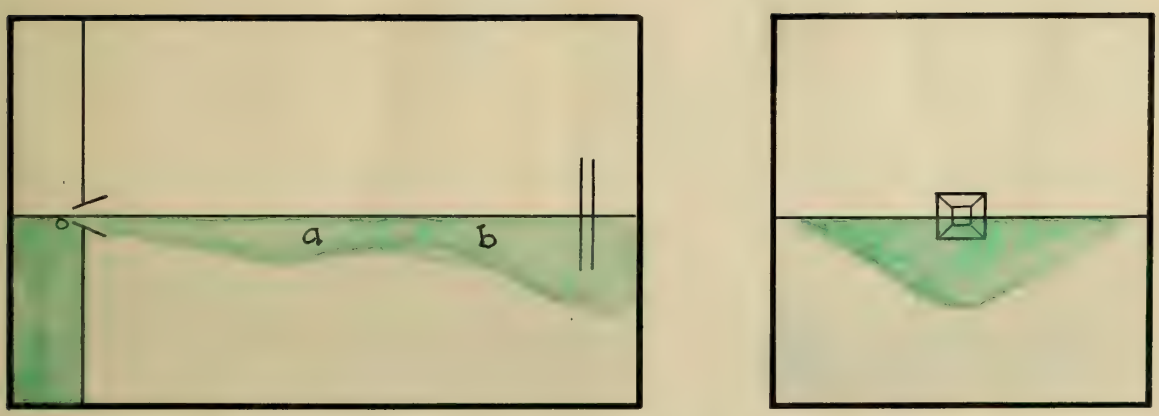


Fig. 2.



Side View.

End View.

Scale 2"=1'

Fig. 3.

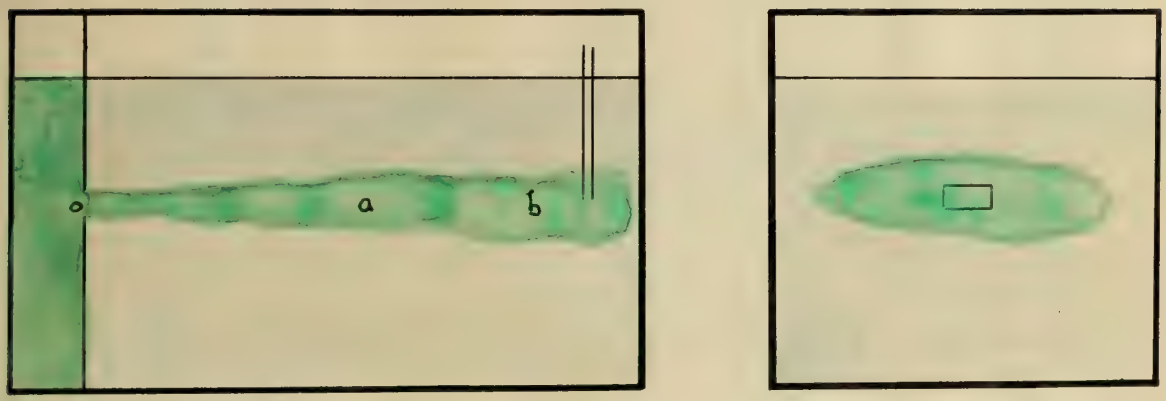
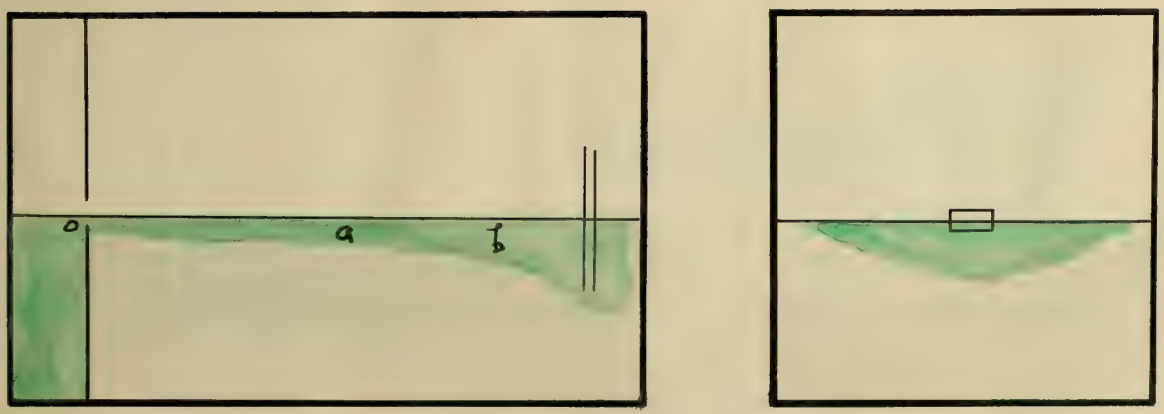


Fig. 4.



Side View.

End View.

Scale ½" = 1'

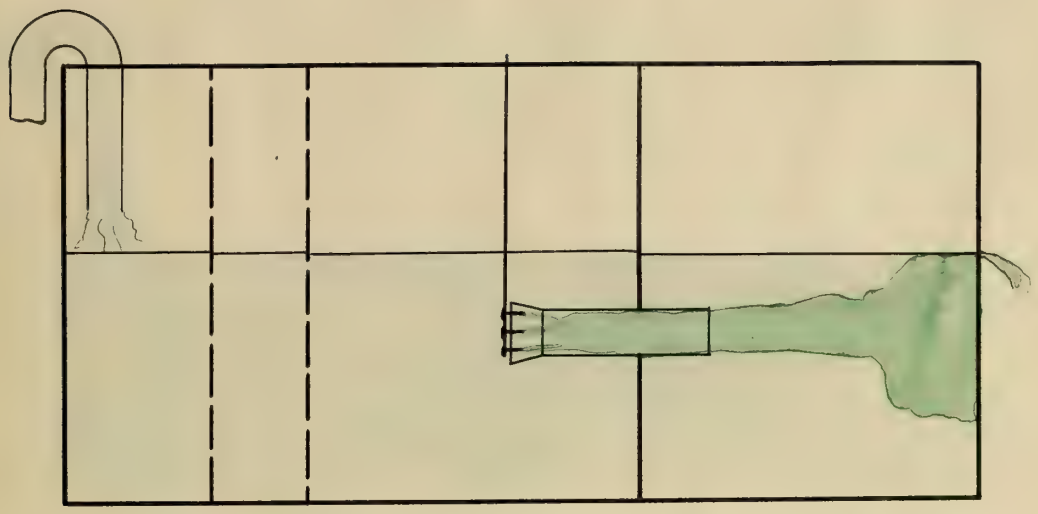


Fig. 5.

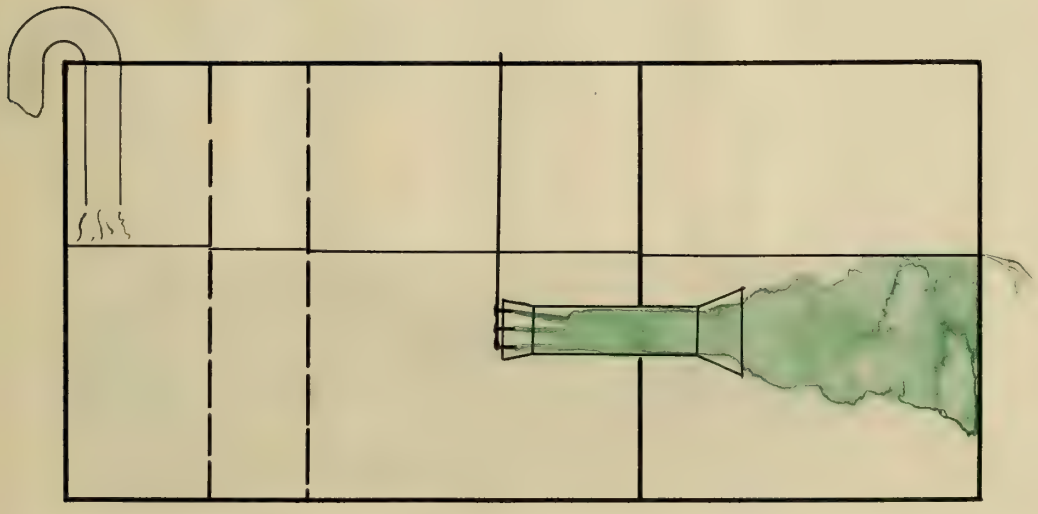
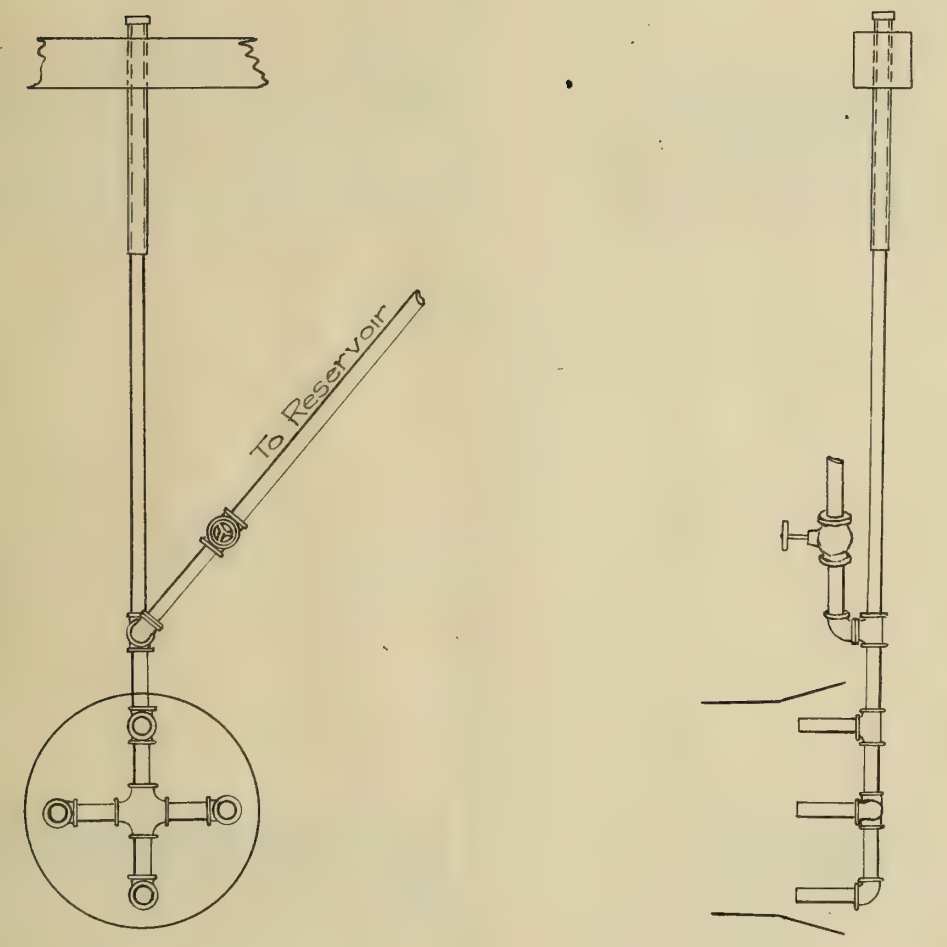


Fig. 6.

Scale 2'=1"

Fig. 7.



Front View

Side View

Device for introducing coloring-matter into orifice.

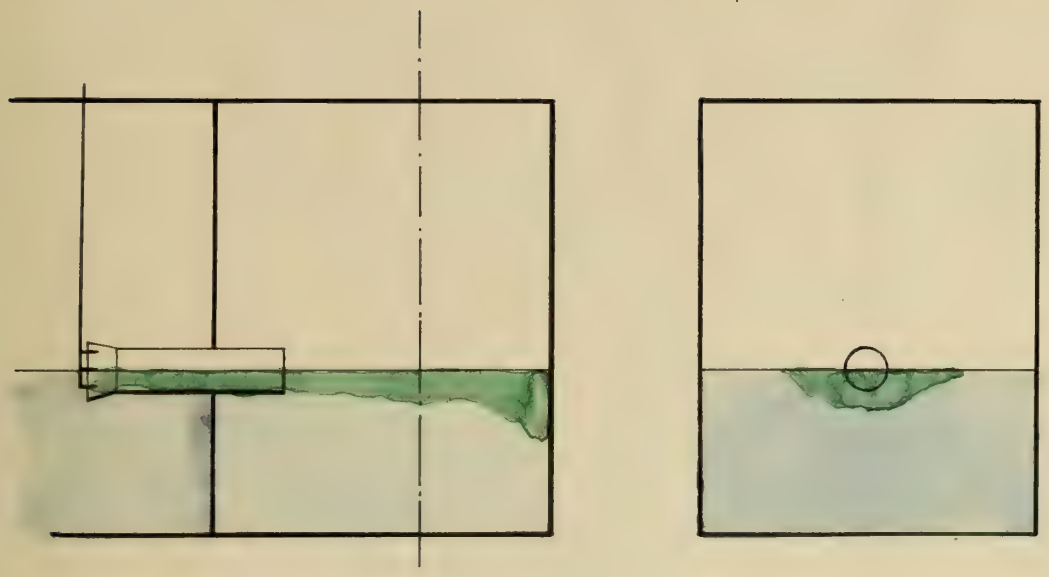


Fig. 8.

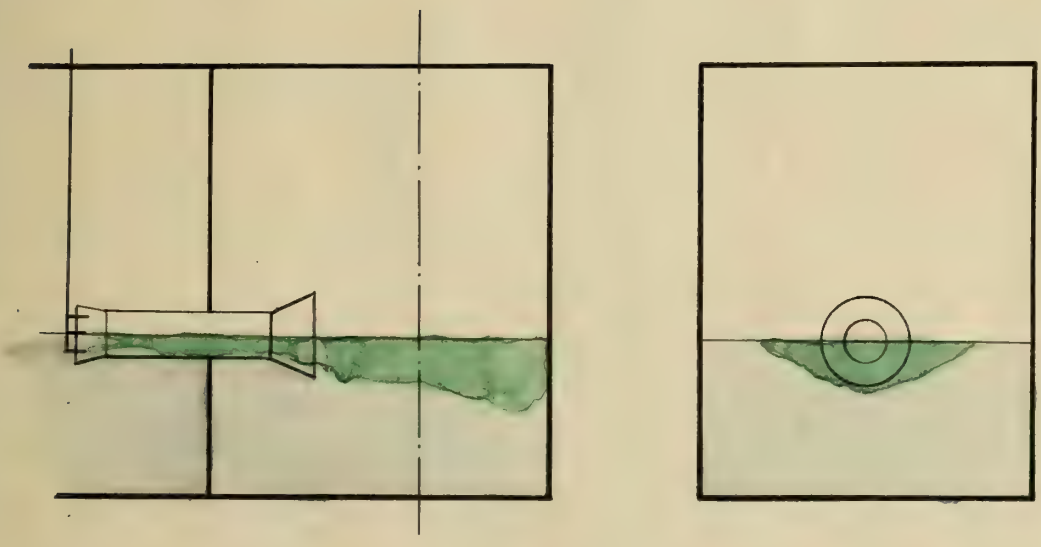
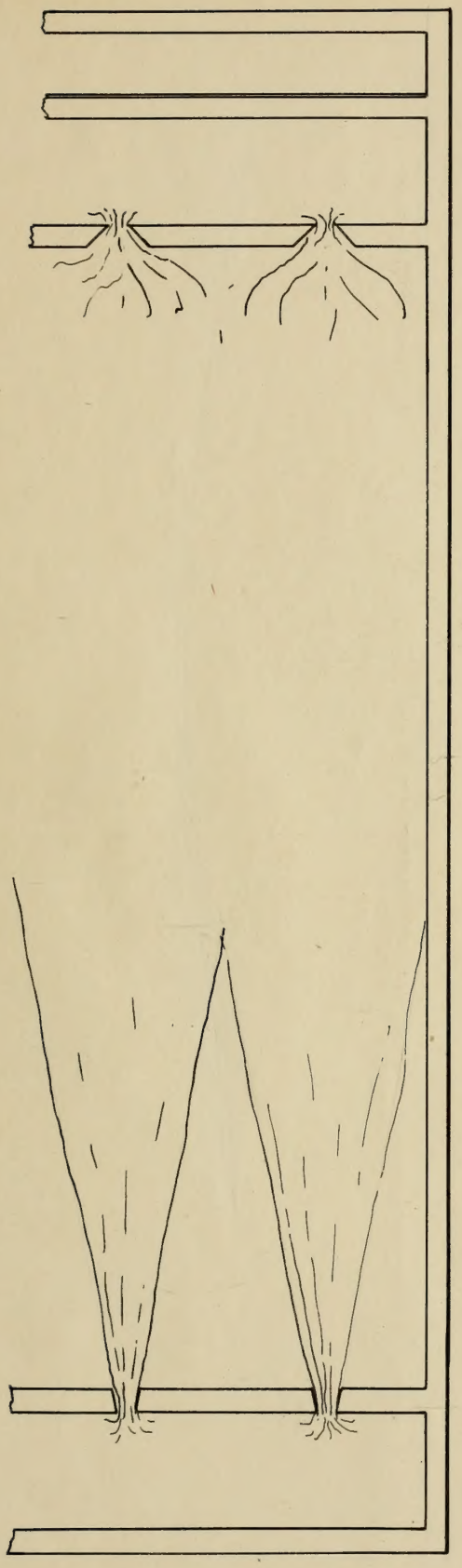


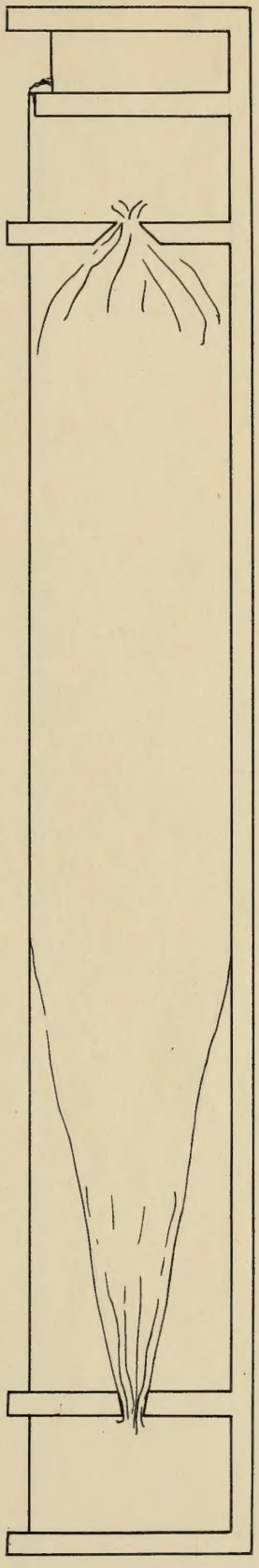
Fig. 9.

Scale 2' = 1"

Fig. 10.



Plan.



Section.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 079093487